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RESEARCH AND DEVELOPMENT FOR FABRICATING A BERYLLIUM AND BERYLLIUM-TITANIUM COMPOSITE PANEL (Final Report, Vol. II)

Prepared under Contract No. NAS 8-20534 by
THE BOEING COMPANY

For

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

April 1968 NASA CR-61637

RESEARCH AND DEVELOPMENT FOR FABRICATING A BERYLLIUM AND BERYLLIUM-TITANIUM COMPOSITE PANEL

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For

Manufacturing Engineering Laboratory

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1.0 INTRODUCTION

The objective of the beryllium panel and beryllium-titanium composite work was to make a preliminary evaluation of formability and electron beam brazing of wrought ingot foil beryllium.

In the first portion of the work an 0.25- by 46.0- by 41.0-inch sheet of wrought beryllium ingot material was formed to an elliptical contour at 1300°F in an integrally heated ceramic die. In the beryllium-titanium composite panel fabrication work a single truss corrugated wrought ingot beryllium foil was sandwiched between titanium face sheets by electron beam brazing.

The hot formed 0.025-inch thick beryllium sheet closely approximated the die contour without preflattening. The process development on fabrication of beryllium-titanium composite panels revealed several major problem areas which were related to: (1) the lack of uniformity in thickness and surface finish of the beryllium; (2) microcracking of beryllium during forming and resistance brazing; and (3) face sheet warpage during electron beam brazing.

2.0 BERYLLIUM PANEL FORMING

This phase of the program was undertaken to determine the hot vacuum forming characteristics of Y-12 wrought beryllium using the high temperature ceramic die designed, fabricated and tested as described in Volume I of this report. The 0.025 by 46.0 by 41.0-inch sheet was positioned on the hot vacuum forming die in the area of the tool which had the minimum contour. The forming process used was with the exception of the 1350°F maximum temperature, the same as the process developed for forming the simulated S-IC titanium gore detailed in Volume I of this report.

The sheet was inspected for surface condition, flatness and thickness variation. This inspection revealed surface discoloration, extreme surface roughness, and poor flatness. Surface finish varied from RMS80 to RMS200. There were three "oil can" areas in the central portion of the sheet that were 12-14 inches long by 4-5 inches wide by 0.500 inches deep.

Manufacturing Plan For Forming

A plaster splash was made of the area of the die in which the forming was to be done. This then became a checking fixture and a shipping fixture. For forming, the part and the die were heated to 1300°F, the selected creep forming temperature for Y-12 wrought beryllium. The overall sequence used for forming is summarized below:

1) thermocouple installation
2) insulation application (Kaowool and Vermiculite)
3) diaphragm installation and sealing
4) heat up to 1300°F
5) vacuum level at 1/2-inch Hg for 30 minutes
6) vacuum level increase to 27 inches Hg over 10 minute span
7) power off and cool with insulation remaining in place
8) inspect.

The formed beryllium is shown in Figure 1 before removing from the forming die. This view shows the thermocouple locations. The thermocouple readings and the heating cycle are shown graphically in Figure 2.

Results Of Forming

All targets in the forming cycle were met. Visual inspection showed the part appeared to be net to the die (Figure 3). With the part on the checking fixture the edges were net and the center was raised slightly. From this visual inspection the hot vacuum forming of Y-12 beryllium was most successful.

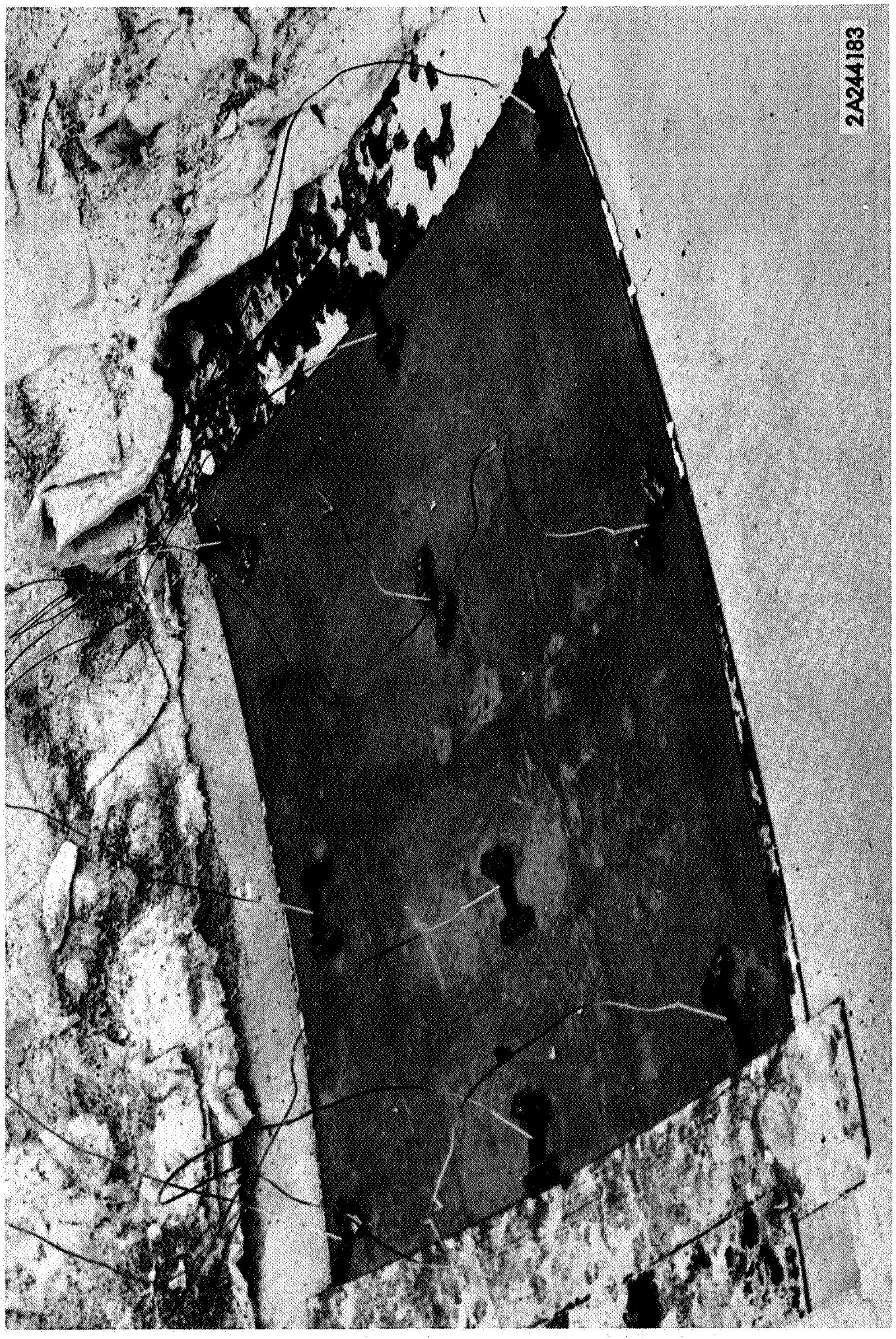


FIGURE 1
FORMED BERYLLIUM PART IN DIE

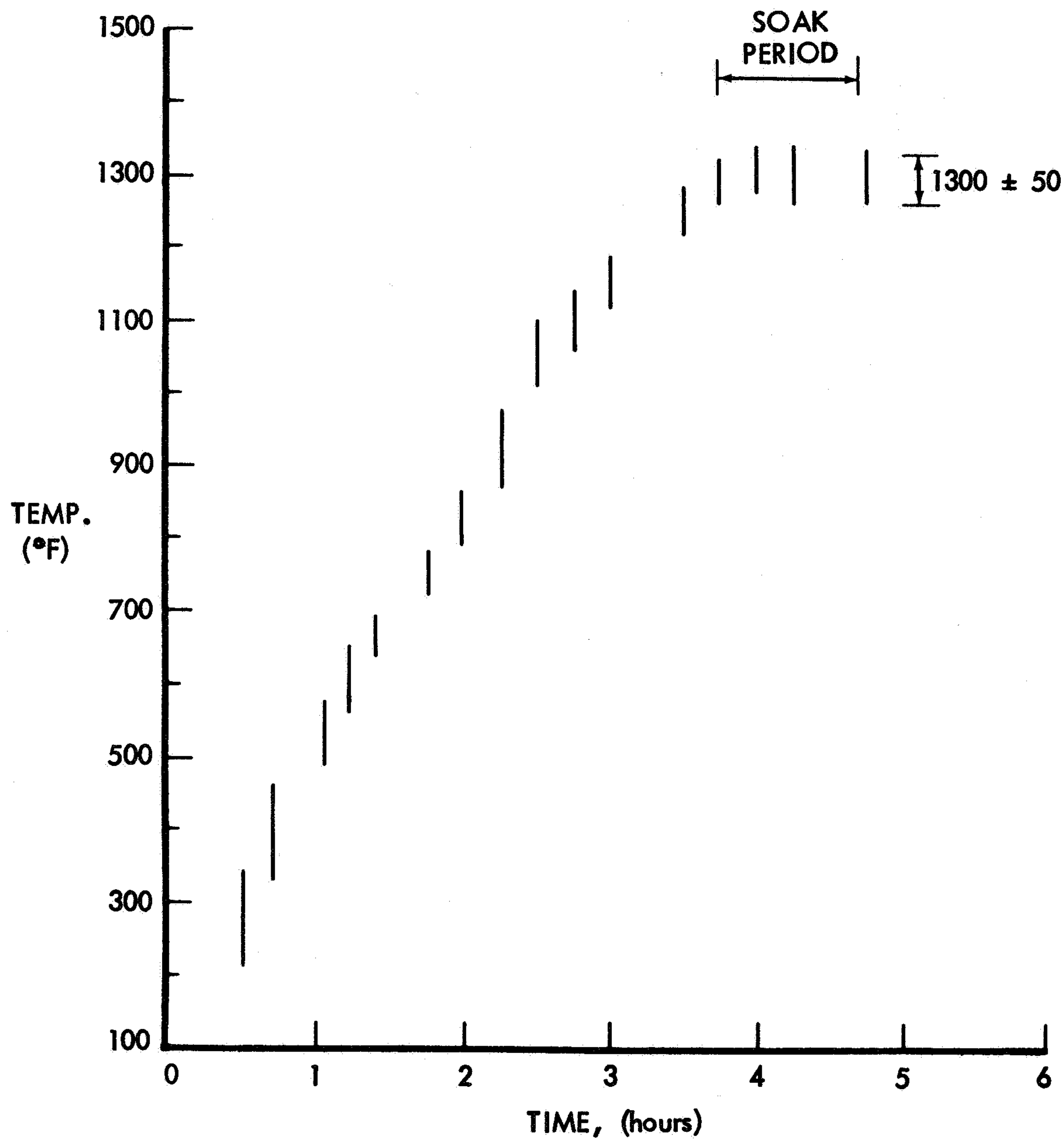


FIGURE 2

Y-12 BERYLLIUM FORMING IN
NASA GORE DIE

FIGURE 3

FORMED BERYLLIUM PANEL 0.025 BY 46.0 BY 41.0 INCHES

Inspection verified that after forming the "oil cans" were removed and only a wrinkle 0.10 inches deep by 1.0-inch wide by 14.0 inches long remained. Post-analysis is that this wrinkle may be removed if a longer soak at 1300°F and full vacuum were used.

3.0 BERYLLIUM-TITANIUM COMPOSITE PANEL FABRICATION

Beryllium-titanium composite structure, consisting of beryllium single-truss core sandwiched between titanium face sheets, offers major weight reduction potential for advanced launch and space vehicles. A research and development program was conducted to engineer and fabricate a beryllium-titanium composite panel to demonstrate the applicability of these materials to typical Saturn V structural requirements.

Recent advances in beryllium technology through joint efforts of the British and the U.S. Atomic Energy Commissions has resulted in the development of beryllium sheet in foil gages with greatly superior formability compared to commercially available hot-pressed powder sheet. This superior formability of ingot sheet resulted in its selection as the core for the composite panel structure.

The design concept selected for study was based on a sub-scale design, aimed at a fuel-tank structure. Figure 4 indicates the possible weight savings (50 percent) attainable by substituting a titanium-beryllium truss-core sandwich for the S-IC fuel-tank side wall. The beryllium-titanium composite panel utilized beryllium corrugated core between titanium alloy face sheets. The demonstration panels were designed to an overall dimension of 12 by 12 inches and a core height of 0.24 inches as shown in Figure 5. This composite structure represents an idealistic use of titanium and beryllium: i.e. the high strength-to-weight titanium sustains the high hoop tension in the tank wall, whereas the high modulus-to-density beryllium sustains only axial compression loads. Panel configurations, tooling concepts, and fabrication procedures were selected on the basis of compatibility with future fuel-tank components.

The joining procedures selected for panel fabrication were resistance brazing for joining of the first titanium face sheet to the beryllium core and electron beam brazing for joining of the second face sheet. This approach was selected since tooling presents no major problems for resistance brazing of the first face sheet and this process would provide maximum flatness for subsequent joining of the second face sheet. The advantage of electron beam brazing is that joining can be accomplished with access to only one side of joint and this would eliminate the need for internal tooling.

3.1 PROCESS DEVELOPMENT

3.1.1 Materials

Beryllium Core - The material used for the corrugated core on the Be/Ti composite panels was beryllium ingot sheet of nominal 0.006-inch thickness. The beryllium sheet was produced at the Atomic Energy Commission Y-12 Plant operated by Union Carbide Corporation at Oak Ridge, Tennessee. The Y-12 beryllium sheet was furnished by NASA on a no-charge basis under terms of the contract. The following material was received:

Description	Quantity
Beryllium Sheet, 0.006 by 42 by 40 inches	1
Beryllium Sheet, 0.006 by 42 by 42 inches	2
Beryllium Sheet, 0.006 by 41 by 27 inches	1

The beryllium sheets were inspected for surface condition, flatness and thickness variations. This inspection revealed surface discoloration, extreme surface roughness (pits and projections), and poor flatness for all sheets. The surface finish varied from RMS 80 to RMS 200. The thickness ranged from 0.005 to 0.009 inches. The extent of the surface roughness and thickness variation was such as to give thickness measurements of 0.009 inches with a flat anvil micrometer and 0.006 inches with a ball micrometer at the same location on the sheet. Past experience indicates that this degree of roughness could adversely affect electrical resistance of contacting surfaces during resistance brazing and the thermal conductivity of contacting surfaces during electron beam brazing.

The flatness of the sheets was poor as shown by Figure 6. The full size sheets varied in flatness up to 0.87 inches when measured with a non-contact, surface contour analyzer. This instrument, developed to measure extremely fragile parts, utilizes a beam of light which travels over the part and measures the distance of a surface from a reference plane. Procedures used in flattening of the beryllium sheet are described in a later section.

Visual and metallographic examinations were conducted on the beryllium sheet in the following conditions: (1) as-received, (2) after flattening and (3) after pickling in HNO_3-HF solution to clean the surface. The material deficiencies were readily apparent, including surface roughness, thickness variations and pinholes.. Typical micrographs of beryllium sheet cross-sections under polarized light are shown in Figure 7.

Titanium Face Sheets - The face sheets for the Be/Ti composite panels were fabricated from 0.015-inch Ti-6Al-4V alloy sheet in the solution annealed condition. The 12.5 by 12.5-inch face sheets were thermally flattened using the same procedures as for the beryllium sheet.

Cleaning Operations

Procedures for cleaning beryllium in preparation for resistance and EB brazing were investigated using methods specified in Boeing Process Specification BAC 5833 "Cleaning of Beryllium". Compositions of cleaning solutions specified in BAC 5833 are given in Table I. Results indicated that pickling with light metal removal will provide improvement in formability and surface appearance but no improvement in surface roughness or thickness variation. More severe pickling improves formability but results in excessive pinhole formation.

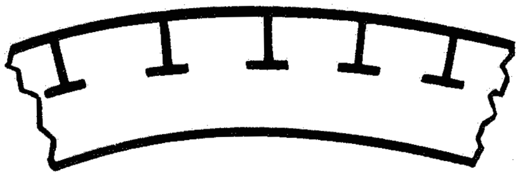
FOR SPECIFIC DESIGN POINT (50 psig, Nc = 10,000 lbs./inch)		WEIGHT SAVING
	ALUMINUM SKIN-RING STIFFENER CONSTRUCTION	0%
	ALL ALUMINUM TRUSS CORE CONSTRUCTION	20%
	ALL TITANIUM TRUSS CORE CONSTRUCTION	37%
	TITANIUM FACE SHEET BERYLLIUM CORE	50%

FIGURE 4

WEIGHT COMPARISON FOR PROPELLANT TANK WALLS

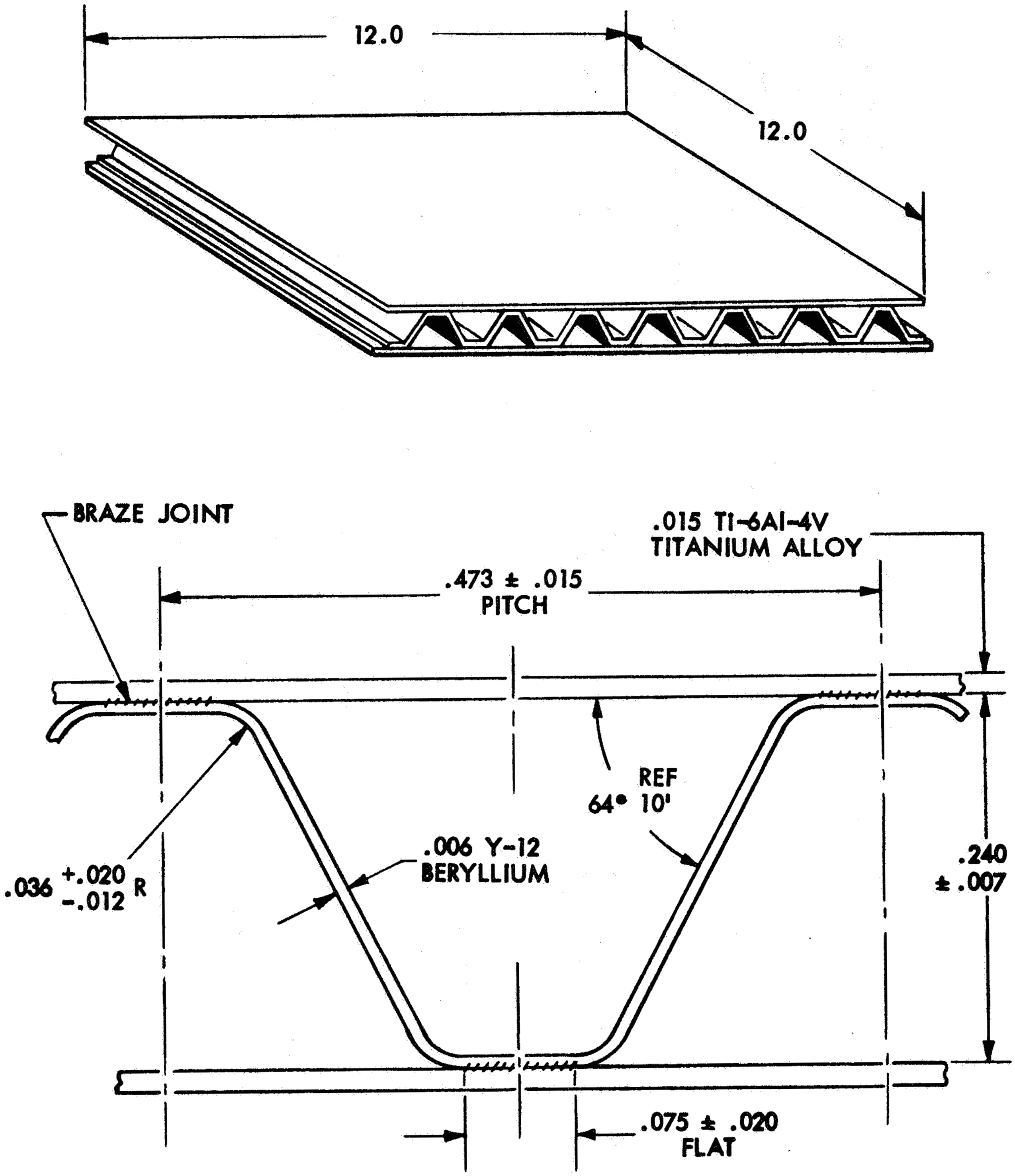


FIGURE 5

DESIGN OF BERYLLIUM-TITANIUM COMPOSITE PANEL

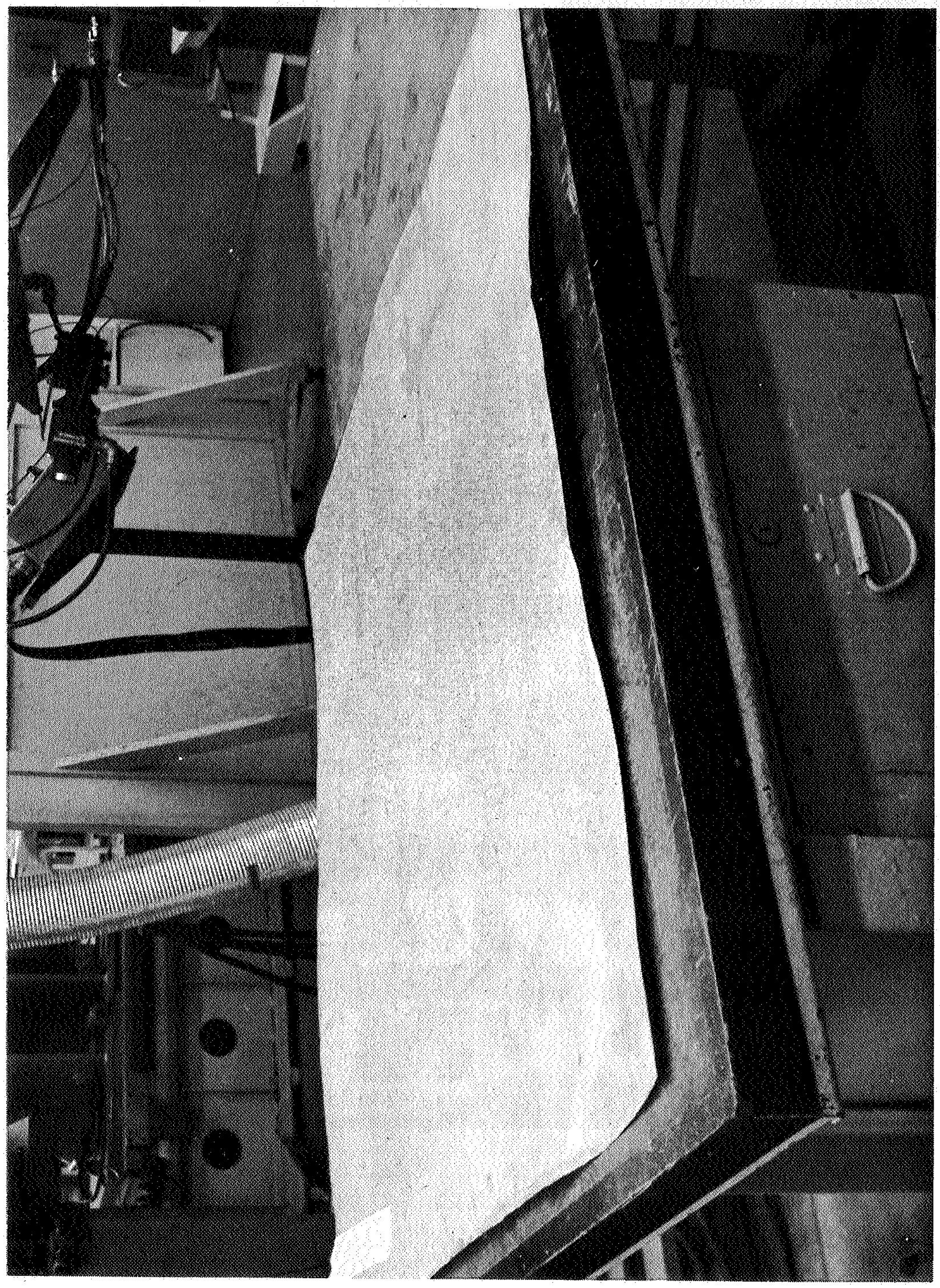
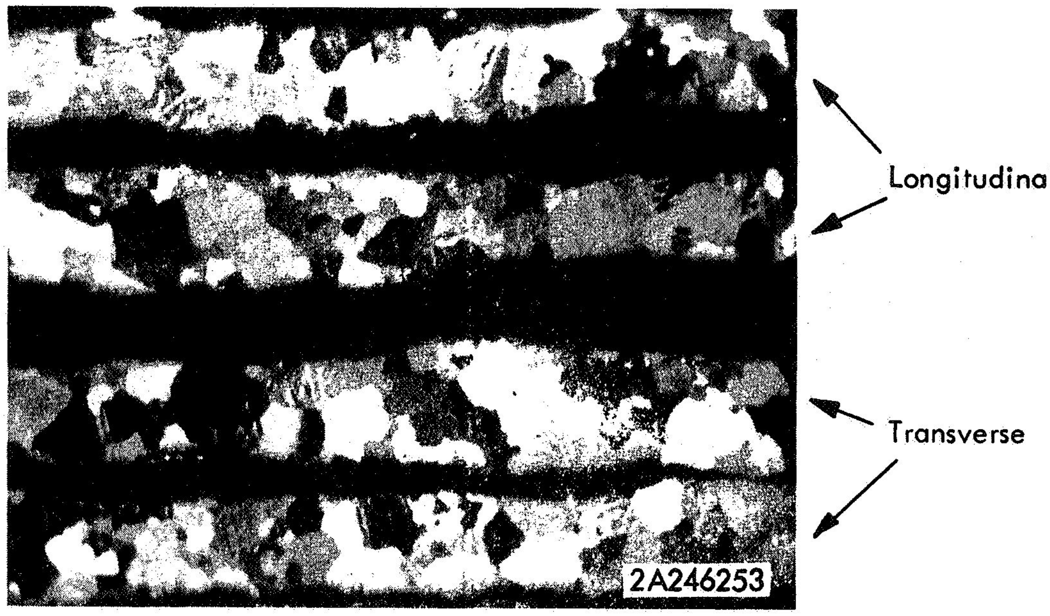


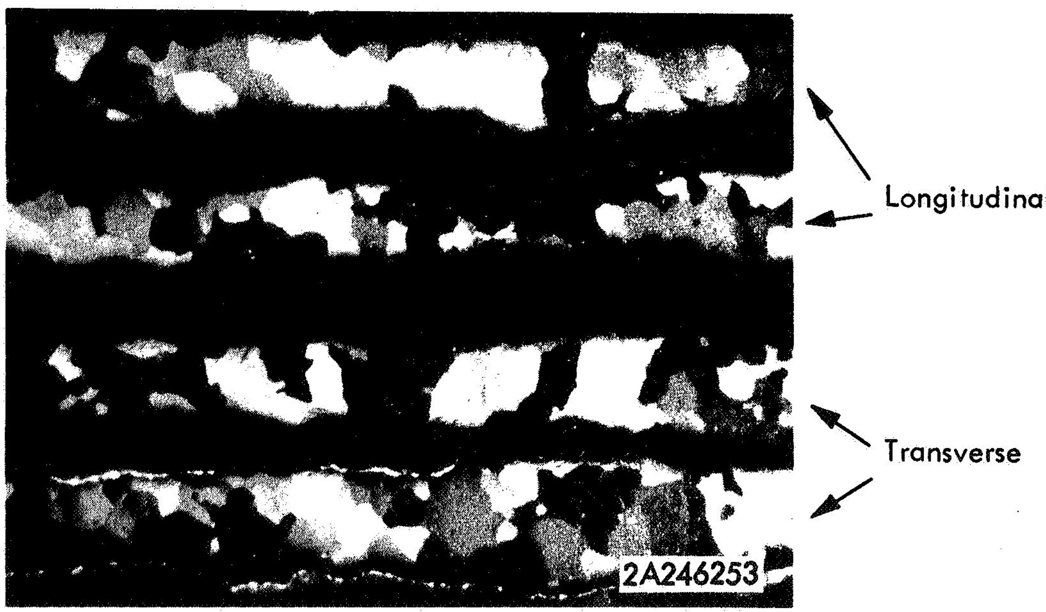
FIGURE 6

TYPICAL BERYLLIUM INGOT SHEET



100X

a) As-Received 0.006-Inch Sheet



100X

b) After Pickling to Remove 0.5 mils/Side

FIGURE 7

MICROSTRUCTURE OF Y-12 BERYLLIUM INGOT SHEET
LIGHT UNDER POLARIZED

TABLE I

BERYLLIUM CLEANING SOLUTIONS

1. NITRIC-HYDROFLUORIC ACID SOLUTION

Nitric Acid (HNO_3 - 40° Be')	30-35 oz/gal
Hydrofluoric Acid (HF-70%)	.03-.04 oz/gal
Water	Balance
Temperature	Room

2. SULFURIC-CHROMIC-PHOSPHORIC ACID SOLUTION

Sulfuric Acid (H_2SO_4) - 66° Be')	8-11 oz/gal
Chromic Acid (CrO_3)	14-17 oz/gal
Phosphoric Acid (H_3PO_4)	160-175 oz/gal
Water	Balance
Temperature	70-110°F

3. AMMONIUM BIFLUORIDE-PHOSPHORIC ACID SOLUTION

Ammonium Bifluoride (NH_4HF_2)	10-13.7 oz/gal
Phosphoric Acid (H3PO_4)	17.6-22 oz/gal
Water	Balance
Temperature	70-100°F

The cleaning procedure for beryllium sheet was established as follows:

1) Pickle in HNO_3-HF solution to remove 0.5 mils/side.
2) Lightly pickle in sulfuric-chromic-phosphoric acid solution for 1 to 3 minutes to brighten surface.

Step 2 was repeated on the beryllium core after the forming operation. These procedures were a compromise to achieve clean surfaces for brazing, improve formability, and to minimize pinhole formation and reduction in sheet thickness.

3.1.2 Core Forming

Formability Evaluation - Initial attempts to form corrugations of the Y-12 beryllium ingot sheet in the as-received condition resulted in microcracks in the radii of nearly all bends. For this reason an investigation was conducted on the forming properties of the beryllium sheet.

The formability evaluation was conducted with 0.006-inch beryllium ingot sheet in two conditions: (1) pickled in HNO_3-HF solution to remove 0.5 mils/side and (2) pickled in ammonium bifluoride solution to remove 1.5 mils/side. Material in the latter condition contained some pinholes due to the more extensive etching and was checked for formability at 500°F only. The bend tests were conducted at temperatures from 500° to 1300°F at a forming rate of 5 inches per minute and a bend angle of 90°. Two punch radii were selected (0.028 and 0.015 inches) to give a nominal part radii of 0.036 and 0.025 inches at 500°F. These punch radii were used for all subsequent tests. The forming parameters were selected to simulate conditions which would be expected in forming beryllium core in the corrugation press.

Results of the forming tests are given in Table II. These data indicate that in order to prevent microcracking when forming corrugations to the design bend radii of 0.036 inches, a forming temperature of 700°F is required for Y-12 beryllium sheet which has been pickled to remove 0.5 mils/side. Light surface cracking would be anticipated when forming corrugations of this material at 500° to 600°F. More severe pickling improves the ability to form the corrugations at the lower temperatures, but results in excessive pinhole formation in the beryllium sheet.

Tooling - Since available data indicated that Y-12 Be should form to a 6t radius at temperatures of 300° to 500°F, a mild steel matched die integrally heated with brass sheathed cartridge elements designed to operate at temperatures up to 500°F was considered adequate. To further reduce tooling costs, it was decided to form only two bends at a time. The disadvantage of this forming method is that the material must be withdrawn from the die and turned over after each stroke of the press. The advantages are less complicated, less expensive tooling, and shorter tooling flow time.

TABLE II

FORMABILITY TESTS OF BERYLLIUM INGOT SHEET

Temp. °F	Gage, Inches	Punch Radius, Inches	Bend Angle, Degrees Approx.	Spring-back Degrees Approx.	Final Part Radius, Inches	Results
500°	.0075 [1]	.028	110	20	.036	Light surface cracks
	"	.015	110	25	.025	Light cracking
600°	"	.028	110	13	.036	One small crack
	"	.015	110	20	.032	Light surface cracks
700°	"	.028	110	8	.036	OK
	"	.015	110	12	.028	OK
900°	"	.028	110	14	.036	OK
	"	.015	110	10	.030	OK
1100°	"	.028	100	4	.036	OK
	"	.015	100	4	.030	OK
1300°	"	.028	90	0	.036	OK
	"	.015	90	0	.025	OK
500°	.0055 [2]	.028	100	20	.060	OK
	"	.015	100	15	.045	OK

[1] Material pickled in HNO_3-HF to remove 0.5 mils/side

[2] Material etched in ammonium bifluoride to remove 1.5 mils/side

Test Conditions:

Ram rate 5 inches/minute

Temperature measured for both part and die temperatures

Bend specimens examined at 40X magnification

A cross section of the forming tool is shown in Figure 8. The die or bottom portion is mounted on the bed of a standard press brake and has provision for fore and aft adjustment to facilitate alignment with the punch or upper portion which is mounted to the movable press ram. As the press ram descends, a spring loaded section of the punch locates and clamps the previous corrugation in the die. This provides automatic and repeatable alignment of the part for the forming of the next two bends which are made as the fixed portion of the punch continues to descend until it bottoms on the die. The ram retracts, the part is removed, turned over and reinserted in the locating part of the die. This is repeated until the part is completely formed.

Flattening - The beryllium sheets were cut to 12.5 by 12.5 and 12.5 by 23-inch panels with a standard knife shear. The edges exhibited some slight burring and minor chipping. Neither was judged serious enough to warrant using a more expensive machining operation to cut panels to size. A 1/4-inch edge margin was left on all sides to allow for later trimming to net dimensions after forming and fabrication.

The parts were rechecked for flatness, this time using a dial indicator with a pressure variation at the tip of 10-50 grams. Maximum out-of-flatness at this time was 0.070 inches.

The parts were cleaned by hand wiping with MEK to remove all adhesive and other foreign matter. They were then vapor degreased in trichloroethylene followed by cleaning in an alkaline solution.

For flattening, the parts were placed between two flat stainless steel plates at a pressure of 0.75 psi in a sand sealed retort, purged with argon and heated to 1300°F. After an hour at 1300°F the retort was removed from the furnace, allowed to cool to room temperature and the parts removed. Temperature was measured by a thermocouple placed inside the retort. Additional discoloration or oxidation was noted which indicated that the argon purge was not 100 percent effective.

Rechecking for flatness with the dial indicator gave a maximum out-of-flatness dimension of 0.055 inches.

Forming - Initial forming trials using scrap material 3 to 4 inches wide indicated excellent uniformity and conformity to drawing dimensions. Variations in both pitch and height dimensions were held to within ± 0.002 inches. A slight uniform slope on the 0.075-inch flat indicated some springback was occurring. It was not considered serious enough to warrant rework of the die. By careful adjustment of the press stroke, this slope can be held to 1 to 2 mils maximum.

A serious problem was discovered though, when the parts were examined under a 30 power microscope. Numerous microcracks were observed on the tension side of the radii.

Variations of speed of press ram travel, preheat time, soak time after forming and temperatures up to 600°F on the part and 700°F on the die did not eliminate the cracking. Annealing at 1450°F for one hour in an argon atmosphere did not show any improvement. Grinding the surface prior to forming resulted in worse cracking. Chemical cleaning was investigated resulting in establishing the compromise procedures discussed in a previous section. This resulted in forming at 600°F part temperature with relatively few microcracks.

Up until this time only small pieces of scrap material, 3 to 4 inches wide, had been used for process development. A temperature gradient in the part ranging from 600°F at the die to room temperature at the edges away from the die and the temperature differential caused by removing the part to turn it after each press stroke, did not appear to be causing any noticeable warping or wrinkling. On the full sized 12.5-inch part however, considerable wrinkling was observed (Figure 9) after the first 2 or 3 bends had been made. As forming progressed, the wrinkles continued to form just ahead of the die and some were trapped under the die causing a bumpy surface on the corrugations. The forming was stopped several times to see if the die could be better adjusted to reduce this condition. At each of these interruptions the part was allowed to cool down. It was soon apparent that in addition to the wrinkles the part had a definite curvature to the corrugations. This curvature advanced as the forming progressed seeming to be always one corrugation behind the punch. The first full-sized panel was of very poor quality when completed. The forming cycle consisted of a .5 second preheat, (punch and die in contact with the material but no pressure applied) a ram travel of two inches per minute and a part temperature of 500°F. It was assumed that wrinkling was due to inequalities in the coefficient of linear expansion caused by the temperature differential and the size of the part. The curvature was apparently due to locked-in stresses from the wrinkling which were aggravated by allowing the part to cool down for examination before forming was complete.

On the second core the preheat time was increased to 10 seconds and a 5-second postheat was added. The part was kept in contact with the die as much as possible. Wrinkling appeared to be about the same but curvature was reduced and uniformity of angles, height and pitch dimensions, was considerably improved. The next step was to add two 500 watt strip heaters in front of the die. The heaters were run at full voltage, the beryllium was overheated and heavy oxide formed in several areas which could not be removed with a light etch. A heavier etch would have increased pinholes. Reducing heaters to 60 percent of rated voltage eliminated overheating. Die temperature was raised to 700°F with resultant part temperature of 600°F. The rest of cycle remained at 10 seconds preheat, 2 inches per minute travel and 5 second postheat with part being removed, turned and returned to contact with die as quickly as possible. Wrinkling was still considered to be excessive but the increased temperature allowed making a smoother part. A slight bow still remained (0.010 - 0.015 inches in 12 inches) but the part was otherwise quite acceptable. One of the parts was thicker than the others (0.009 inches as against .006 - .008 inches)

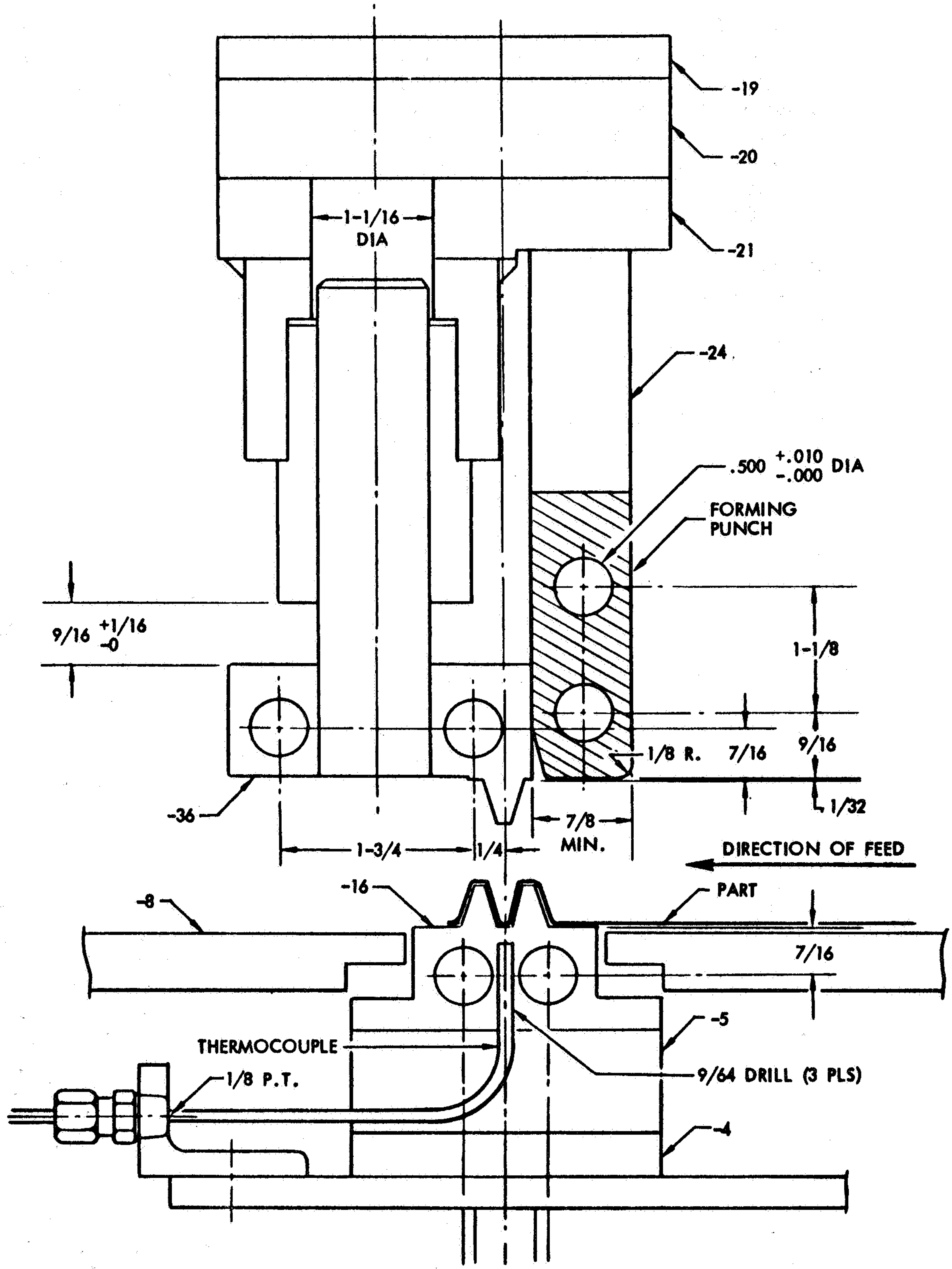


FIGURE 8

SKETCH OF CORRUGATION FORMING TOOL

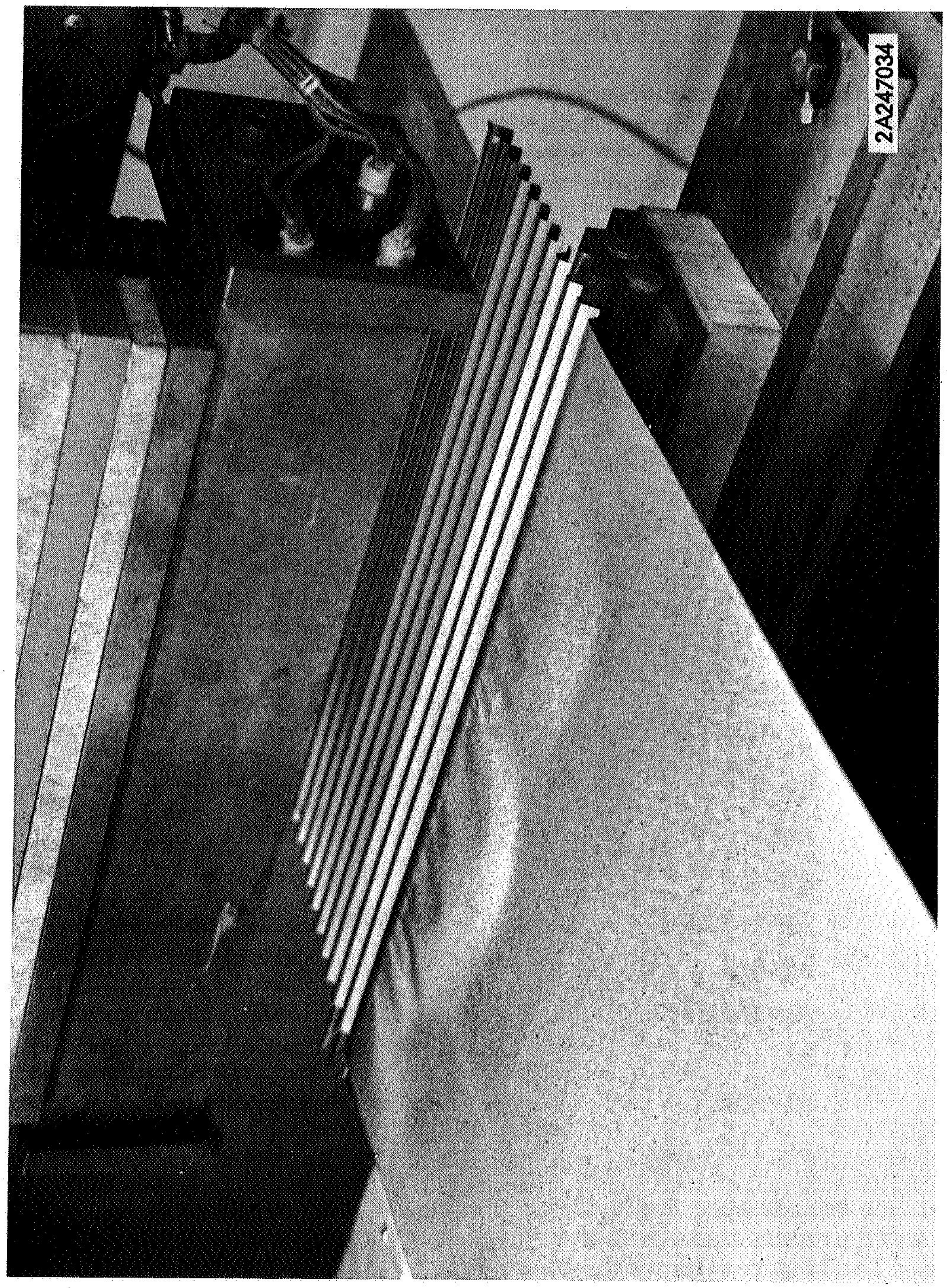


FIGURE 9
WRINKLING OF 0.006-INCH BERYLLIUM SHEET
DURING CORE FORMING

and seemed to be stiffer. This part did not wrinkle as badly but did exhibit some cracking. Further development should be considered so that the part can be heated uniformly and continuously throughout the forming period.

3.2 RESISTANCE BRAZING

Beryllium to titanium resistance brazing was performed with a Sciaky multimode 200-kva resistance spot welding machine equipped with digital timing controls. This welder, shown in Figure 10, has three welding modes: single-polarity single-impulse, multiple impulse, and single-impulse with current decay.

A Mallory 100 copper alloy electrode (RWMA Class 3) 5/8 inches in diameter with 6-inch tip radius was used for the upper electrode which contacted the titanium sheet. A tungsten tip electrode machined to fit the beryllium corrugated core was used for the lower electrode. The tungsten tip was dressed to a 2-inch radius. The upper electrode was used in a spring-loaded electrode holder which could be adjusted to obtain any electrode force in the range of 20 to 250 pounds.

A review was made of available information on braze alloys which have been used for brazing of beryllium and titanium. These data indicated that Al-, Ag-, and Au- base braze alloys showed the greatest promise for resistance brazing of Be/Ti joints. Preliminary resistance brazing tests were conducted with the following braze alloys in the form of 0.002-inch foil:

Composition	Melting Temp. °F
Ag	1761
Ag-0.2Li	1700-1740
Ag-1Li	1500-1580
Ag-2Li	1400
Ag-7.5Cu-0.2Li	1435-1635
Ag-5Al-0.5Mn	1440-1510
Ag-10Mn-5Ti	1745-1750
Al	1220
Al-12Si	1080
Au-18Ni	950

Resistance brazed specimens of 0.006-inch Be sheet to 0.015-inch Ti-6Al-4V sheet were prepared and evaluated by peel testing and metallographic examination. The best results were obtained with Ag- base braze alloys. The brazing techniques were not optimized to the extent that spot brazes could be made consistently without microcracks in the Be. Metallographic examination disclosed that material quality, particularly surface roughness and surface imperfections contributed to formation of these microcracks. Braze alloys Ag-1Li, Ag-5Al-0.5Mn and Ag-7.5Cu-0.2Li were selected for further process development.

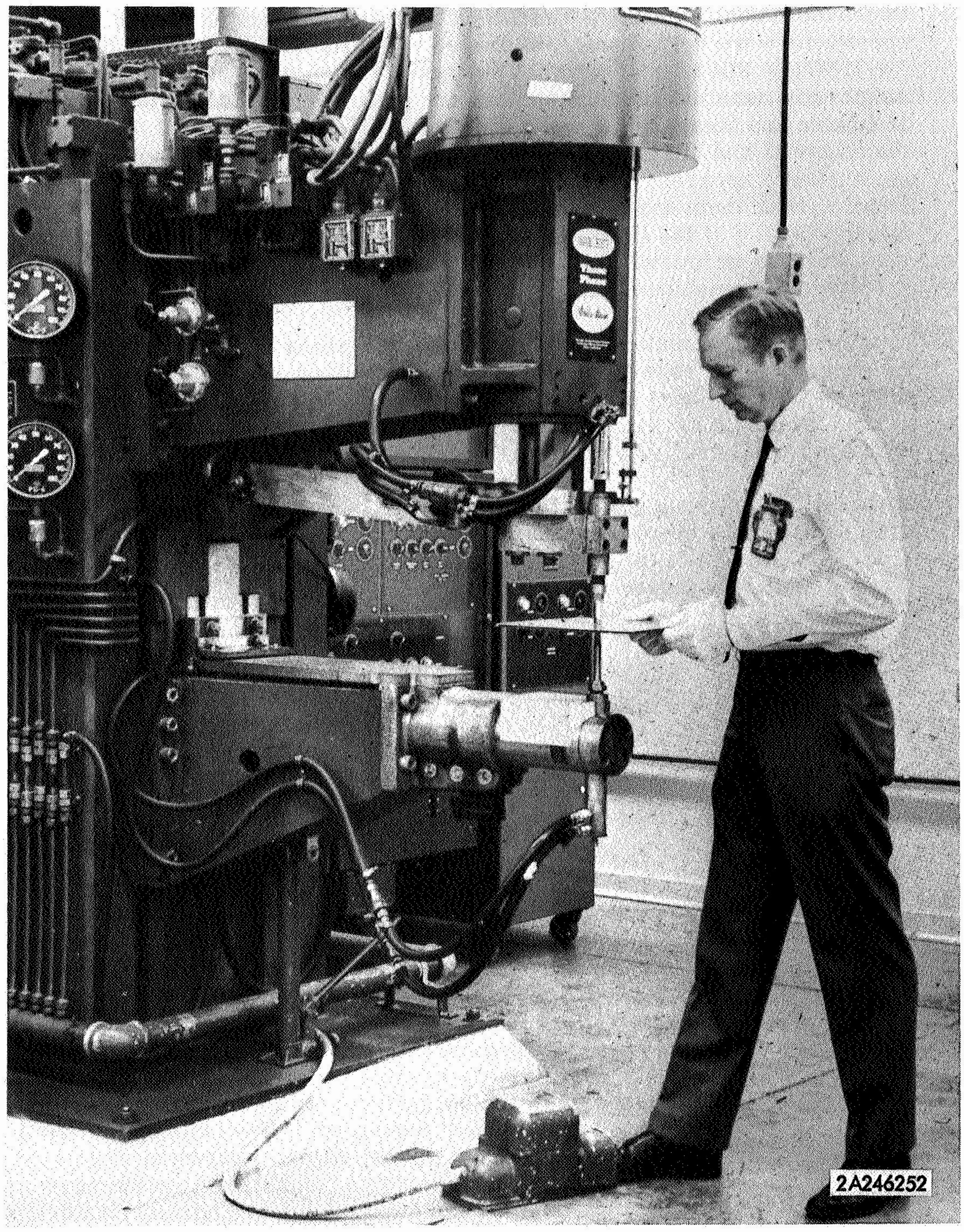


FIGURE 10

SCIAKY MULTI-MODE 200 KVA SPOT WELDING MACHINE

Improved machine settings were developed and peel test and tensile shear specimens were resistance spot brazed using Ag-1Li, Ag-5Al-0.5Mn and Ag-7.5Cu-0.2Li braze alloys. Test results for both Be/Ti and Be/Be single-spot tensile shear specimens are given in Table III. The same mode of failure and comparable shear strength levels were obtained for each of the material and braze alloy combinations. No major differences in joint quality were apparent for the three braze alloys as a result of peel tests, tensile shear tests and metallographic examination. Some tendency for microcracking of the Be in or adjacent to the spot brazes was displayed even with the improved brazing techniques. The Ag-1Li braze alloy was selected for resistance brazing of the Be/Ti panels.

Micrographs of resistance spot brazed Be/Ti joints are shown in Figure 11. The heat affected zone in the titanium results from the thickness difference between the beryllium and the titanium sheets. Figure 11c is a resistance brazed joint with excessive heat input, where melting of the titanium and entrapment of braze alloy has taken place within the titanium sheet.

The resistance brazing parameters established for fabrication of the Be/Ti panels (first face sheet only) were as follows:

Electrode Force	70 lbs
Machine Settings	10% Phase Shift
Pre-Heat	1 Cycle Current Time
	2 Impulses
Braze Heat	87% Phase Shift
	1 Cycle Current Time
	1 Impulse
Cool Time Between Impulses	1/2 Cycle
Transformer Tap Setting	Series

A condensor discharge spot welding machine was used to spot tack the braze alloy foil to the beryllium core (Figure 12). Ag-1Li 0.002-inch foil was cut into 0.12-inch wide strips and tack brazed to the 0.075-inch flats on the corrugations.

A brazing fixture was used to assemble the core and face sheet and to hold the assembly during initial resistance brazing. After sufficient resistance spot brazes had been made to retain core alignment the panel was removed from the fixture and resistance brazing completed. The brazing fixture is shown in Figure 13. Spot brazing of the panel edges is shown in Figure 14 and the center portion of the panel in Figure 15. Additional spot brazes were made at approximately 2-inch spacings on every other corrugation to minimize distortion prior to completing resistance brazing at 0.25-inch spot intervals.

TABLE III

TENSILE SHEAT TESTS OF RESISTANCE SPOT BRAZED
Be/Ti AND Be/Be SPECIMENS

Material Combination	Braze Alloy	Number of Specimens	Average Failure Load, lbs	Range of Failure Load, lbs.	Failure Mode
Be/Ti	Ag-1Li	4	27	20/31	Be tear-out
Be/Ti	Ag-5Al-.5Mn	5	28	25/33	Be tear-out
Be/Ti	Ag-7.5Cu-.1Li	4	29	21/34	Be tear-out
Be/Be	Ag-1Li	4	29	23/36	Be tear
Be/Be	Ag-5Al-.5Mn	5	28	25/33	Be tear

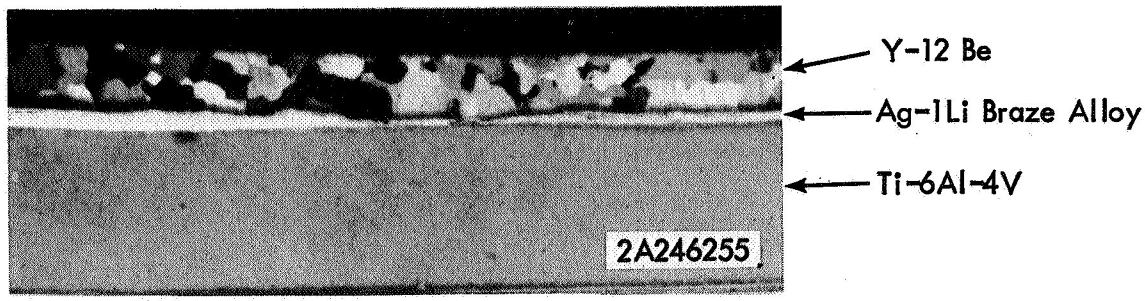
Material

AEC Y-12 Ingot Be sheet, .0065-inch thickness after cleaning in (1) nitric-HF acid and (2) chromic-sulfuric-phosphoric acid.

Ti-6Al-4V sheet, .015-inch thickness.

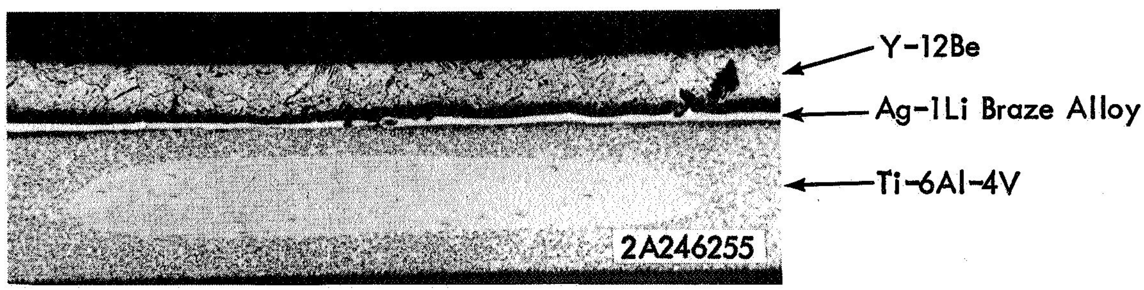
Resistance Spot Brazing

Single spot brazes using copper electrode on Ti and tungsten electrode on Be. Diameter of spot brazes .04-.05 inches.



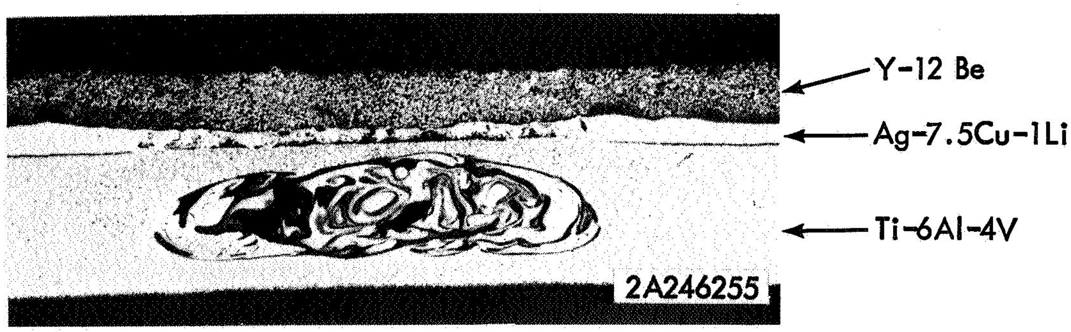
No Etch 50X

(a) Typical Be/Ti Resistance Spot Braze Shown Under Polarized Light



Krolls Etch 50X

(b) Typical Be/Ti Resistance Spot Braze Etched to Show Heat Affected Zone in the Titanium Alloy



Krolls Etch 50X

(c) Be/Ti Resistance Spot Braze with Excessive Heat Input. Etched to Show Heat Affected Zone in Titanium Alloy

FIGURE 11

MICROGRAPHS OF RESISTANCE SPOT BRAZED Be/Ti JOINTS

FIGURE 12
RESISTANCE SPOT TACKING OF BRAZE ALLOY TO BERYLLIUM CORE

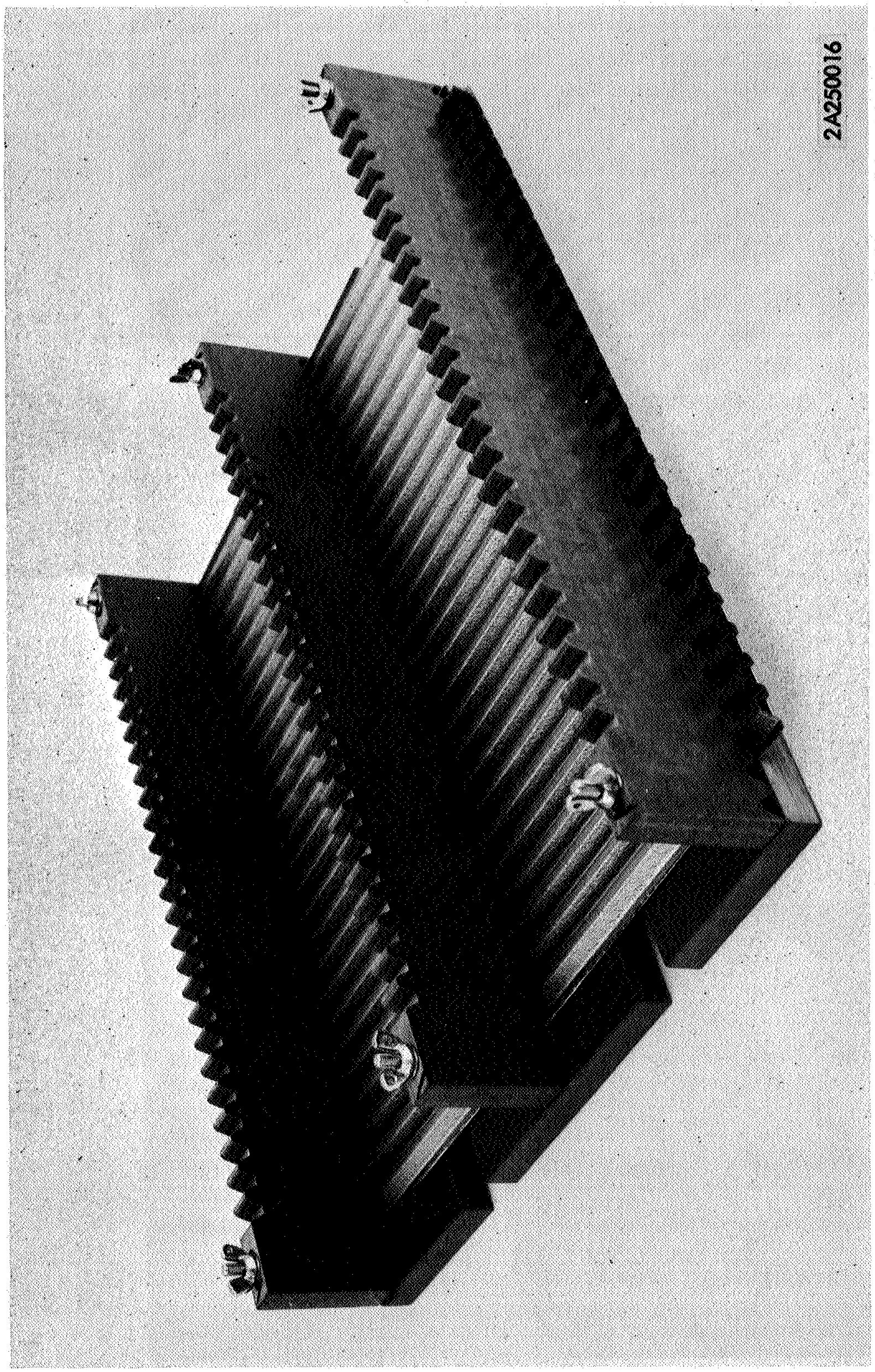


FIGURE 13

RESISTANCE BRAZING FIXTURE FOR BERYLLIUM-TITANIUM COMPOSITE PANEL

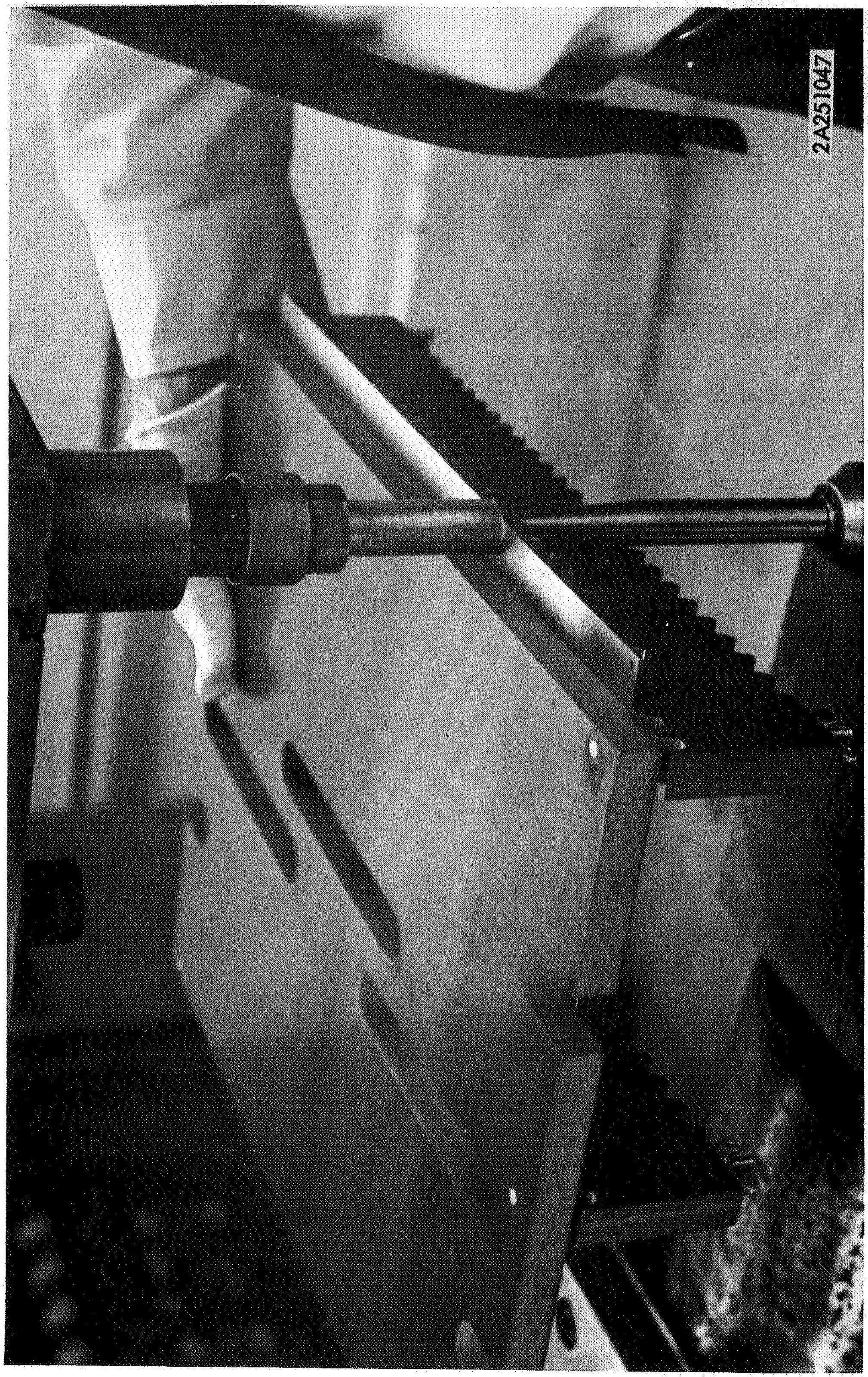


FIGURE 14

RESISTANCE BRAZING OF BERYLLIUM-TITANIUM COMPOSITE PANEL

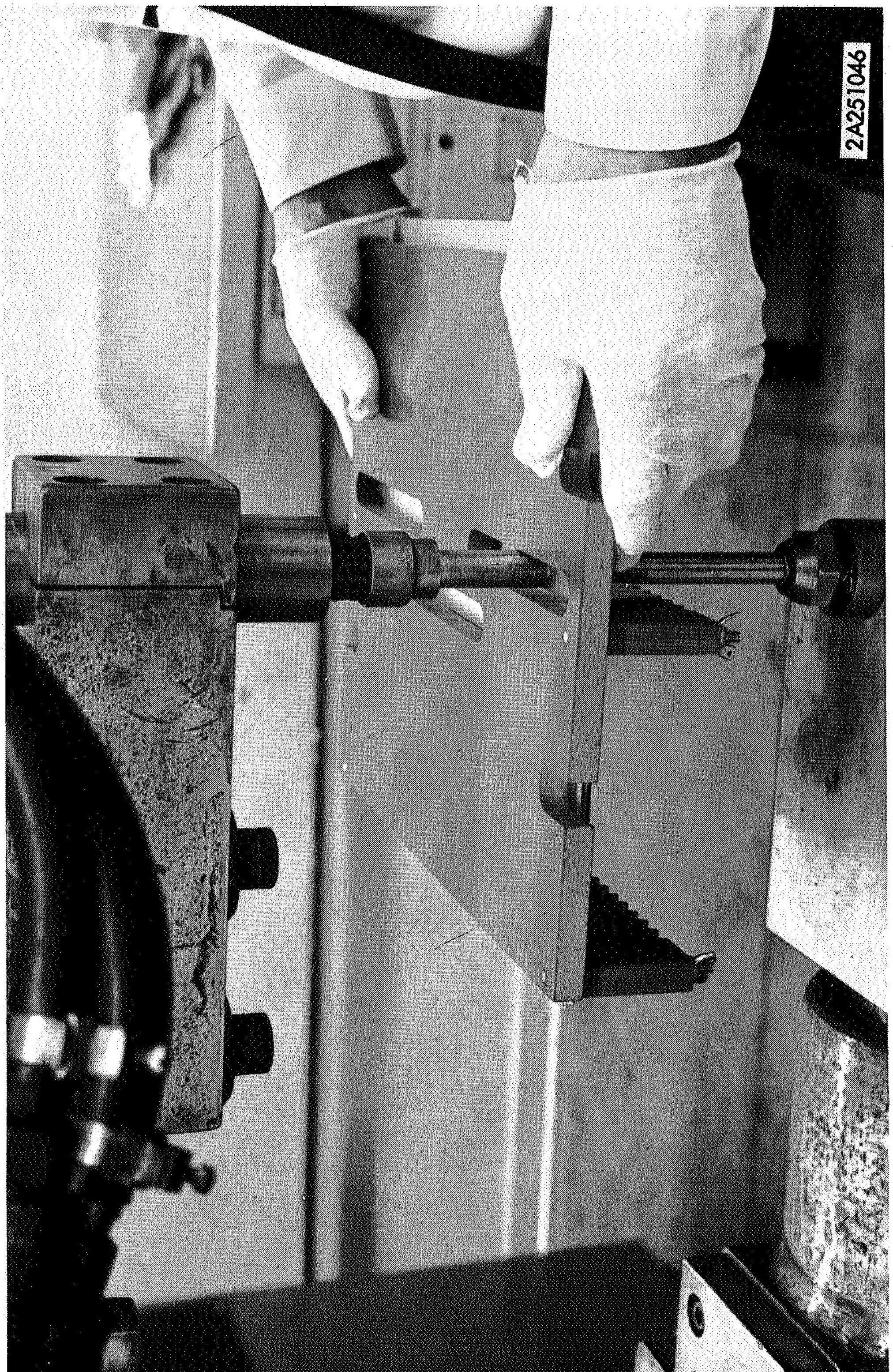


FIGURE 15

RESISTANCE BRAZING OF BERYLLIUM-TITANIUM COMPOSITE PANEL

Four 12.5 by 12.5-inch Be/Ti open face panels were successfully resistance brazed using these techniques. The flatness of the resistance brazed panels was exceptionally good as shown by photographs of a completed panel in Figures 16 and 17.

3.3 ELECTRON BEAM BRAZING

Electron beam brazing of the second Ti-6Al-4V face sheet to the beryllium core was performed with a Sciaky 30KW (60KV @ 500 ma) electron beam welding unit with a 30 by 30 by 48-inch rectangular vacuum chamber. Linear motion is provided on two axes by a travelling work platen and moveable electron beam gun.

Auxiliary features include an optical viewing system and a beam oscillator. Tooling for electron beam brazing consisted of a hold-down fixture and a spring-loaded pressure jig with revolving wheels. The pressure jig was attached to the EB gun and provided continuous pressure by the spring-loaded revolving wheels to the area adjacent to the electron beam. The EB brazing tooling set-up is shown in Figure 18. A close-up view of the pressure jig and EB gun is shown in Figure 19.

In order to avoid equipment contamination during tool tryout and preliminary process development, corrugated core fabricated from 0.006-inch C.P. titanium was substituted for beryllium core. The titanium corrugated core was formed using the Be forming tools. The dimensional conformance was relatively poor compared to the Be corrugations but was adequate for the preliminary EB brazing work.

Titanium corrugated core and Ti-6Al-4V face sheets were EB brazed using Ag-1Li and Ag-5Al-0.5Mn braze alloy foil. Single pass (continuous) EB brazes resulted in excessive warpage of the face sheets. This warpage was minimized by EB spot brazing at 0.25-inch intervals. Peel tests and metallographic examination revealed good bonding of the C.P. Ti/Ti-6Al-4V brazed joints.

Because of the warpage encountered during EB brazing, two lower melting point braze alloys, Au-12Ge (M.P. 673°F) and Ag-24Cu-15In (M.P. 1300°F) were evaluated. The Au-12Ge braze alloy was unsatisfactory due to brittleness of the brazed joints. Electron beam spot brazing with Ag-24Cu-15In braze alloy resulted in ductile Ti/Ti-6Al-4V braze joints with somewhat less heat input and panel warpage than for Ag-1Li alloy. Continuous pass EB brazing resulted in excessive face sheet warpage for both of the low melting point alloys. The Ag-24Cu-15In braze alloy was selected for EB brazing of the final face sheet for the Be/Ti panels.

The next step in the process development was the EB brazing of Ti face sheets to the beryllium core. The best results were obtained with 0.001-inch Ag-24Cu-15In braze alloy and EB spot brazing at 0.25-inch intervals along each corrugation. The spot brazes were automatically spaced with a preset power on and off time while the work platten travelled at a rate of 7 inches per minute. Using these techniques a face sheet was EB brazed to a 6 by 12-inch open face (resistance brazed) Be/Ti try-out panel. The inner rows of spot brazes were satisfactorily bonded but some unbonded spots were obtained in the outer row on each side of the panel due to face sheet warpage. Sections were cut from the panel and metallographic examination and peel tests were conducted. The EB brazed Be/Ti joints displayed good bonding although some spot brazes contained voids which appeared to be due to irregular contact between the face sheet and core. The EB spot brazes contained twice the bond area of the resistance spot brazes. Micrographs of typical Be/Ti EB brazed joints are shown in Figure 20. As a result of these tests the Ag-24Cu-15In braze alloy was selected for EB brazing of the final face sheet for the Be/Ti panels.

The close-out face sheet was EB brazed to the first 12.5 by 12.5-inch Be/Ti panel. This panel (Panel #1) contained a core which had been rejected due to excessive corrugation curvature and for this reason was used primarily as a process try-out panel. The core warpage and corrugation curvature provided some difficulty in obtaining consistent rows of spot brazes but the principal problem was again face sheet warpage. About 6 inches in width of good EB spot brazes were obtained and then the remaining area showed excessive panel distortion and intermittent spot brazes which were not bonded.

Panel #2 was electron beam brazed (final face sheet to resistance brazed open-face panel) using revised tooling procedures and sequencing of the initial tack-down brazes in order to minimize face sheet warpage. Two parallel hold-down bars with machined back-up bars were used to supplement the pressure jig attached to the EB gun in holding the face sheet in contact with the core (Figure 18). Significant improvement was obtained compared to Panel #1, but the face sheet warpage was still excessive. Attempts to repair areas of poor bonding resulted in additional face sheet warpage, panel distortion and localized core crushing. The panel quality was not considered satisfactory. The electron beam brazed side of Panel #2 is shown in Figure 21 and the resistance braze side is shown in Figure 22.

Panel #3 was electron beam brazed using further modifications in tooling and braze sequencing to reduce face sheet warpage. Spacers were used on all four sides of the panel to permit additional hold-down pressure and eliminate core crushing. Face sheet warpage was again excessive and areas of poor bonding were evident. Although the quality of Panel #3 was somewhat better than Panel #2, the quality was still not considered satisfactory.

A review was made of progress on electron beam brazing of Be/Ti truss core panels and possible approaches which might be used for further process improvement. It was concluded that there was a low probability that the excessive face sheet warpage encountered with the EB brazing process could be controlled for large panels. For this reason, process development on electron beam brazing of Be/Ti composite panels was terminated.

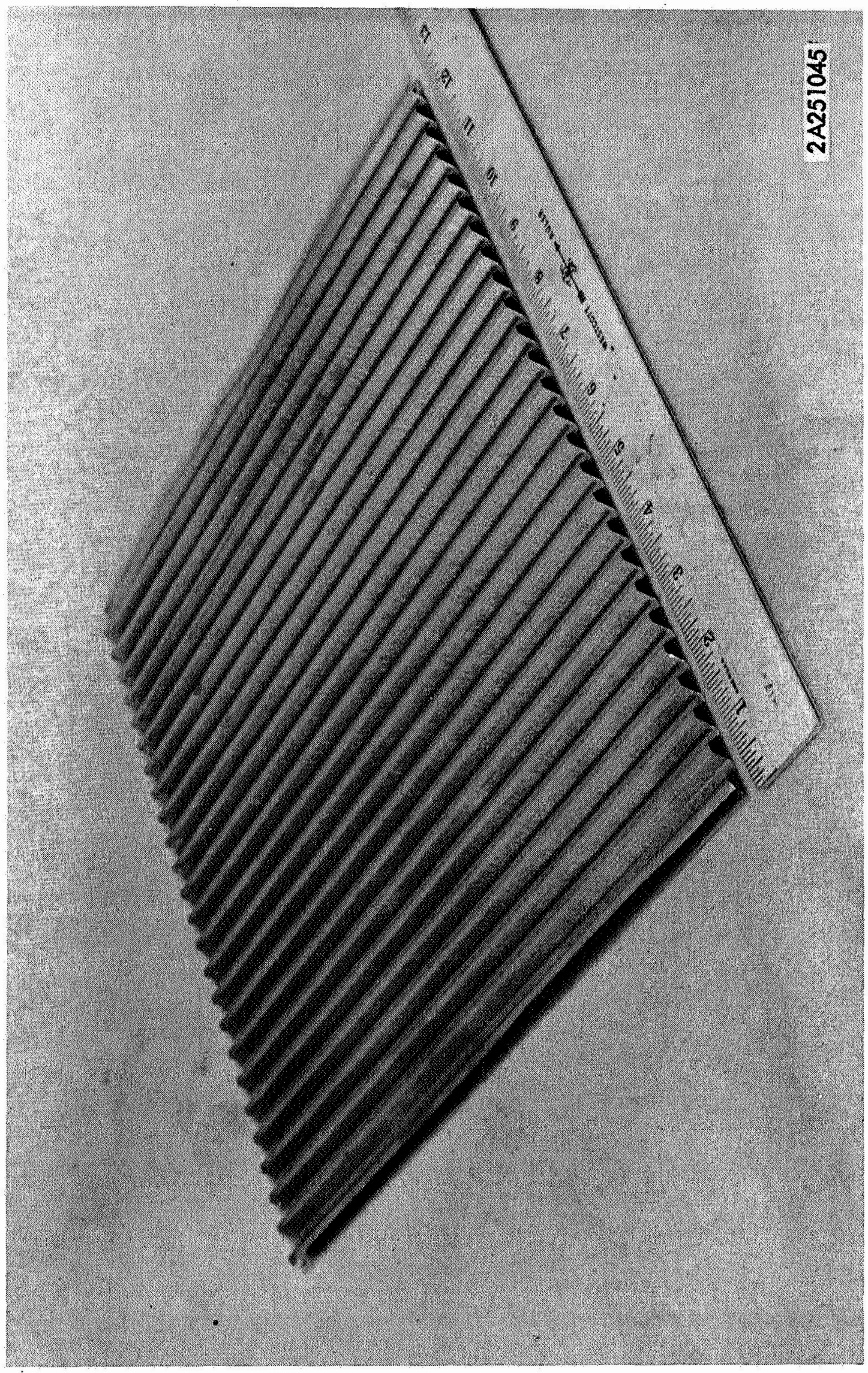


FIGURE 16

RESISTANCE BRAZED OPEN-FACE BERYLLIUM-TITANIUM COMPOSITE PANEL

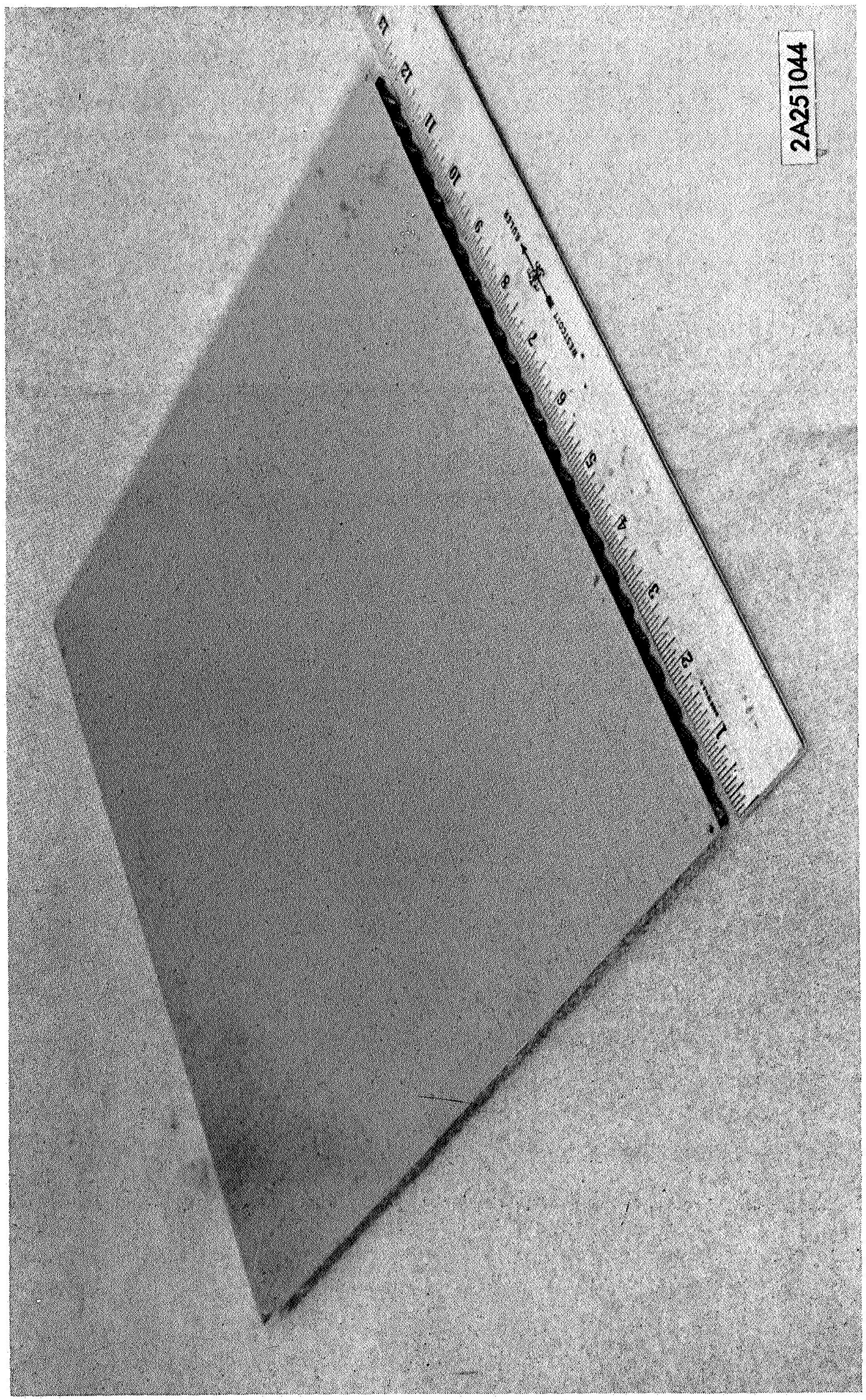


FIGURE 17
RESISTANCE BRAZED OPEN-FACE BERYLLIUM-TITANIUM COMPOSITE PANEL

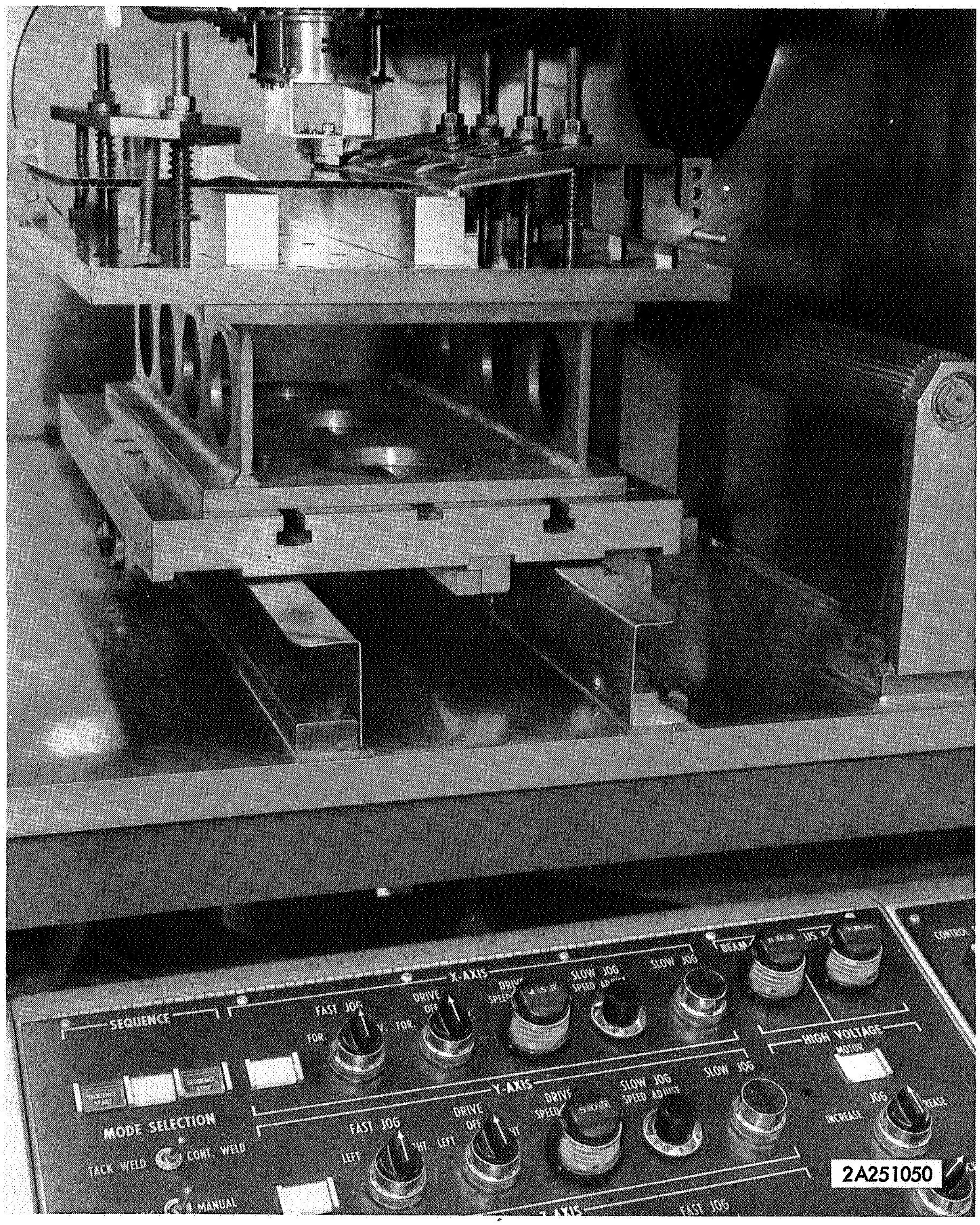


FIGURE 18

TOOLING SET-UP FOR ELECTRON BEAM BRAZING OF BERYLLIUM-TITANIUM COMPOSITE PANEL

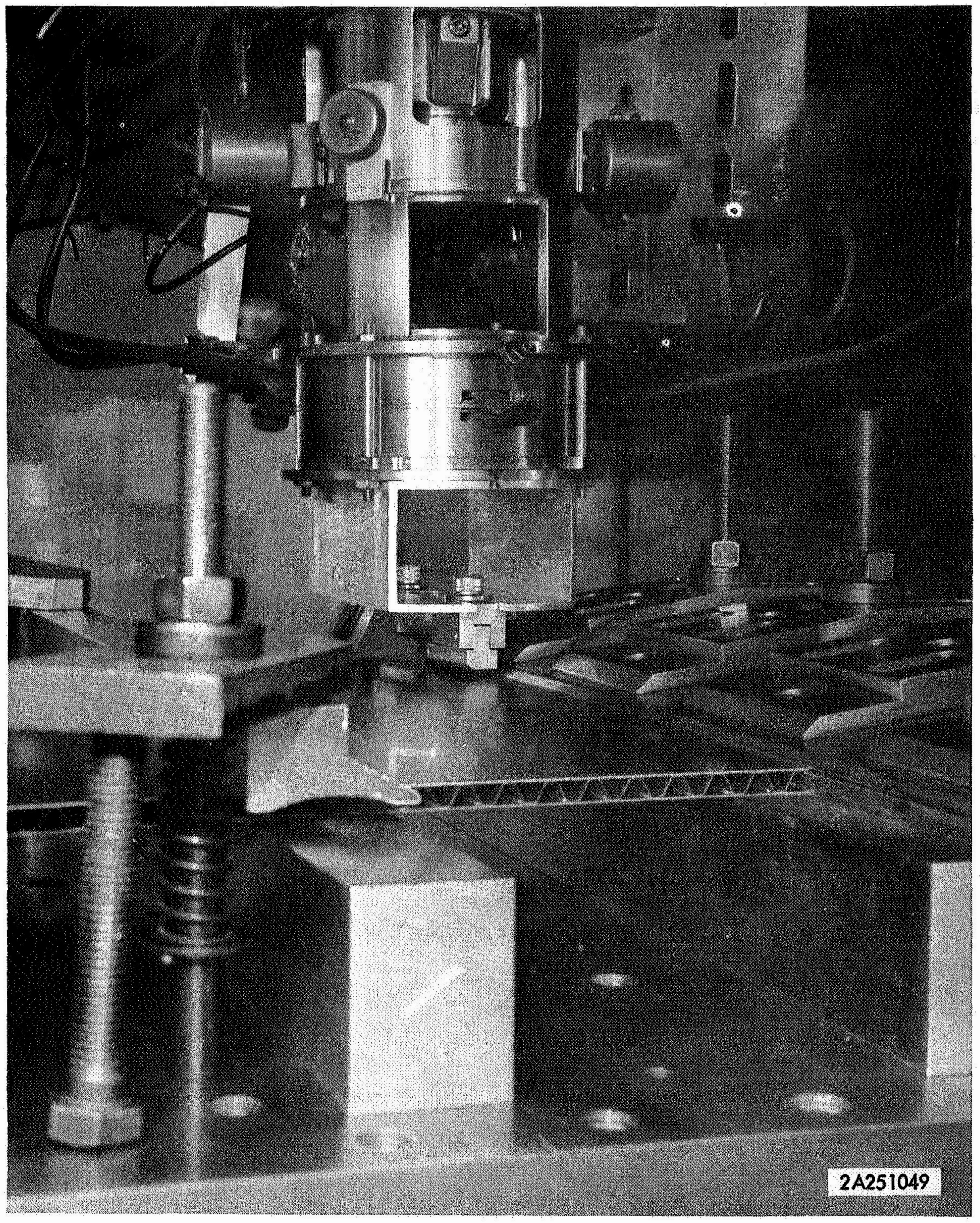
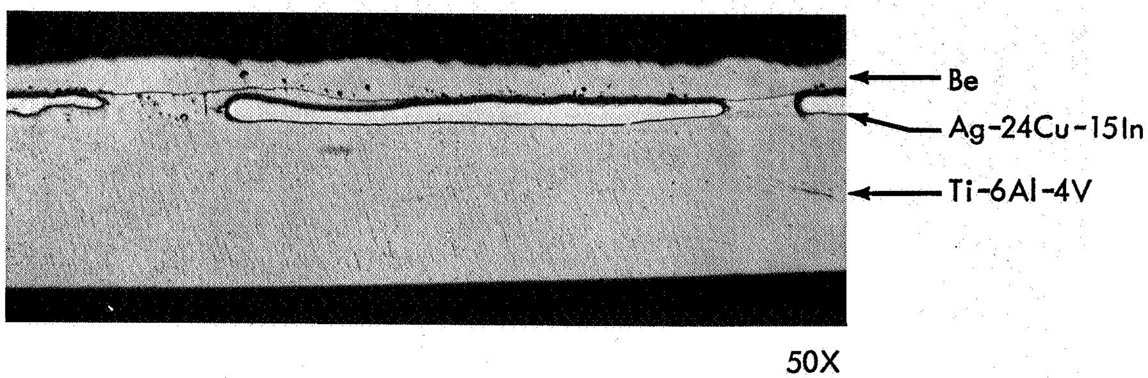
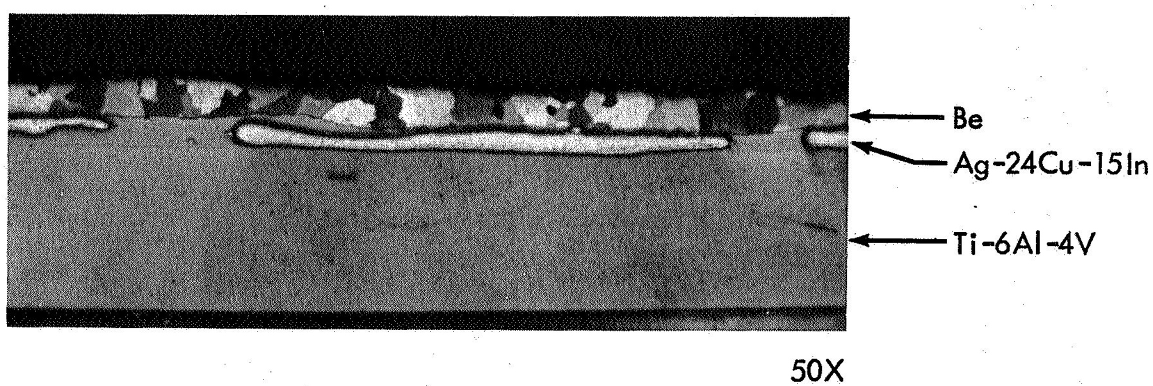


FIGURE 19

PRESSURE JIG FOR ELECTRON BEAM BRAZING OF BERYLLIUM-TITANIUM COMPOSITE PANEL



a) Typical Be/Ti Electron Beam Brazed Joint Under Plain Light



b) Typical Be/Ti Electron Beam Brazed Joint Under Polarized Light

FIGURE 20

MICROGRAPHS OF ELECTRON BEAM BRAZED Be/Ti JOINTS

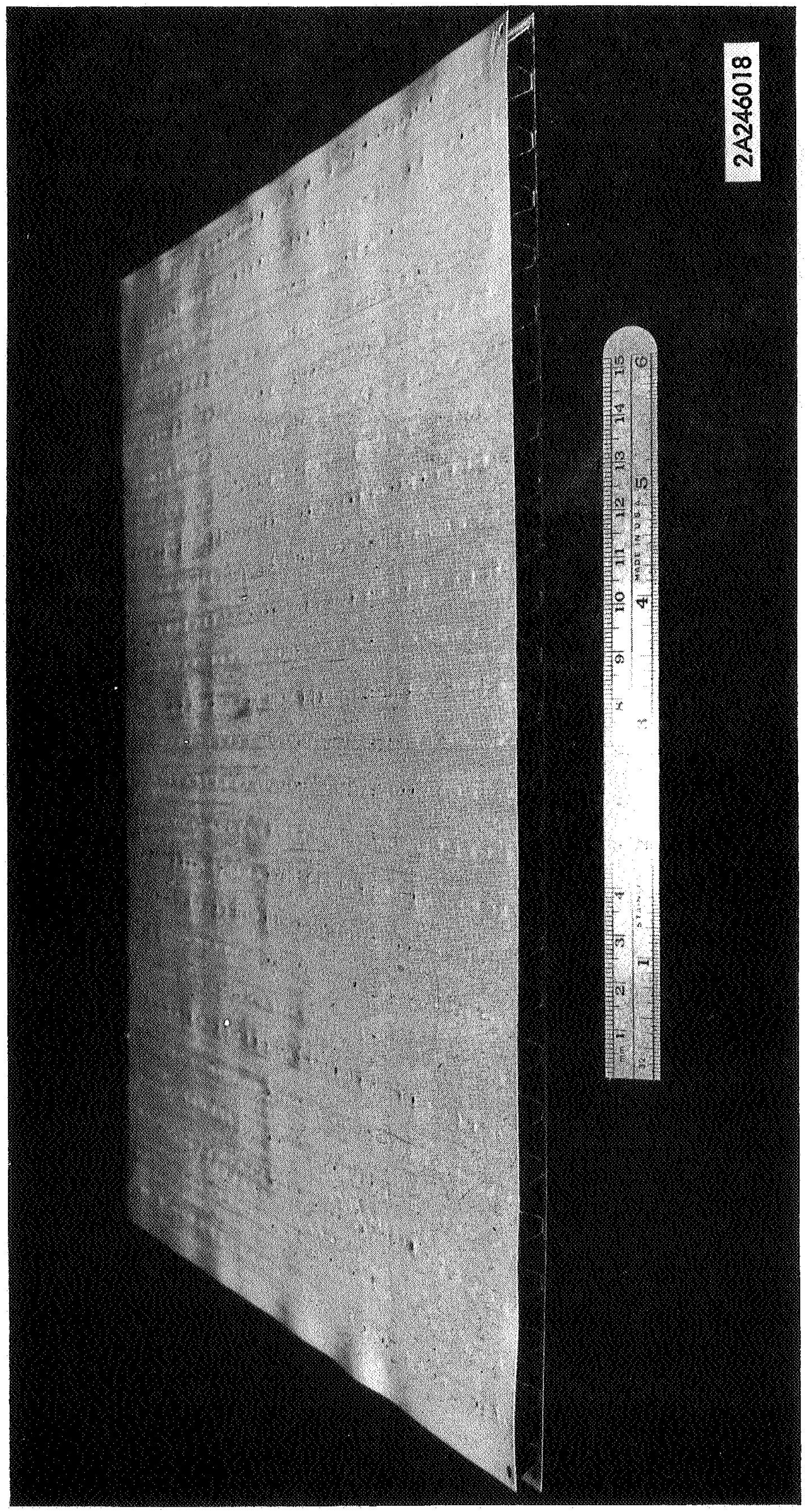


FIGURE 21
BERYLLIUM-TITANIUM COMPOSITE PANEL -
ELECTRON BEAM BRAZED SIDE

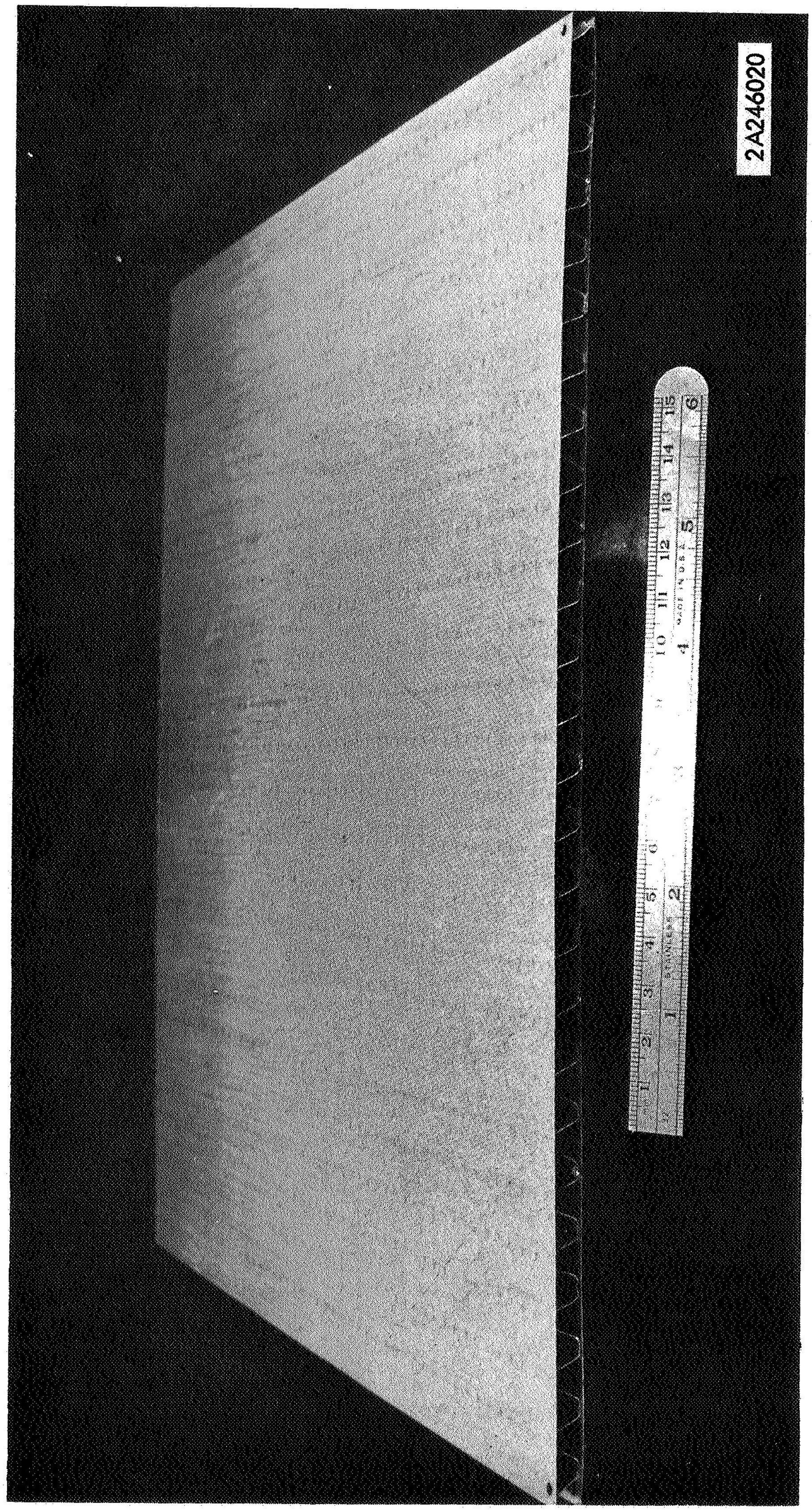


FIGURE 22
BERYLLIUM-TITANIUM COMPOSITE PANEL -
RESISTANCE BRAZED SIDE

The electron beam welding facility was cleaned in accordance with decontamination procedures established by Industrial Hygiene. Wipe samples taken on both cleaned and uncleaned areas of the chamber and tooling revealed no detectable beryllium contamination. This freedom from beryllium contamination was expected since no actual melting of beryllium had been performed in the electron beam welding facility. In brazing of the Be/Ti panels the beam of electrons impinges only on the titanium face sheets and no accidental melting of the beryllium was encountered.

Machining of Brazed Panel

Panels #2 and #3 were machined to 12 by 12-inch net dimensions using an abrasive cutoff wheel and stabilizing the core with wax. The parallelism of the machined sides was held to a total TIR (total indicator reading) of 0.002 inches. No special tooling was required although the problem of clamping the parts for machining was rather difficult due to the warped condition of both panels. Some EB braze failures were encountered during machining of Panel #3 but it was believed that this was due primarily to the high residual stresses during electron beam brazing.

Machining without stabilizing the edges was tried but resulted in some chipping and cracking of the edges of the Be core. Machining tests were conducted using two commercially available low-melting metallic fillers to stabilize the edges. The materials performed satisfactorily but as no convenient method was found to completely remove them from the panel after machining, the metallic fillers were abandoned in favor of wax.

After stabilizing the core with wax, the panel was clamped to the bed of a milling machine and one of the edges parallel to the core corrugation was trimmed with an abrasive cutoff wheel. The remaining edges were trimmed to net dimensions by indexing from the first machined surface. The abrasive wheel used was a 1/16-inch thick by 12-inch diameter Norton 37C60-O8B wheel, rotating at 4700 surface feet per minute and cooled by a flood of water soluble oil. The table feed was 3-1/4 inches per minute. After melting most of the wax out, the remainder was removed with an aliphatic solvent.

4.0 CONCLUSIONS

Process development on fabrication of beryllium-titanium composite panels has revealed several major problem areas which have hindered development of successful fabrication techniques. The most serious problems are related to:

1) Quality of Y-12 beryllium ingot sheet; i.e. surface roughness, thickness variations and pinholes.
2) Microcracking of beryllium during forming and resistance brazing.
3) Face sheet warpage during electron beam brazing.

It is believed that significant improvements in the quality of beryllium ingot sheet can be achieved by the ingot sheet fabricators. Improved sheet rolling techniques and additional rolling facilities will be required to fabricate sheet to meet structural requirements.

Difficulties were encountered with forming of Y-12 beryllium ingot sheet which are attributed to material quality. Studies indicated the forming problems could be solved by use of higher forming temperatures or more extensive surface pickling. Formability tests indicated a forming temperature of 700° to 1100°F was required to prevent microcracking but the fabricated tooling was limited to 600°F maximum. Excessive pinholing resulted when greater than 0.5 mils/side was removed by pickling. As a result, a compromise of forming temperature (600°F) and pickling (0.5 mils/side) had to be used to fabricate the beryllium core for the Be/Ti composite panels.

The tendency for microcracking of the beryllium sheet should be materially lessened by improvement in sheet quality. Further development effort should result in the successful development of resistance brazing techniques for beryllium.

The excessive face sheet warpage resulting from localized heating during electron beam brazing appears to be an insurmountable problem for large structural panels. Utilization of lower melting point brazing alloys will reduce the face sheet warpage but not to the extent of making electron beam brazing of large panels a practical process. The stress concentrations induced in such panels by the localized heating will greatly reduce the load-carrying capabilities of the compressive loaded structures.

Three 12 by 12-inch beryllium-titanium composite panels were fabricated but none of these panels was considered to be of satisfactory quality due to face sheet warpage during electron beam brazing. Panel #2 was accepted by NASA-MSFC as meeting the contract requirements. Panel #3 appeared better than Panel #2 after brazing, but bond failures were encountered during machining due to the high residual stresses in electron beam brazed face sheet.

Techniques were reviewed for resistance spot brazing of the second face sheet to the core. Fabrication of large truss core panels completely by resistance spot brazing appears to be feasible. Several tooling concepts were considered and the use of a tungsten rod held by a copper mandrel inserted in the corrugation has a good chance of success. In view of the good results in resistance brazing of the first titanium face sheet, it is anticipated that a relatively small additional effort will be required to develop processing techniques for brazing the final face sheet of a demonstration panel.

5.0 RECOMMENDATIONS

1) Electron beam brazing process development should be discontinued since face sheet warpage is so severe with this technique that it is unlikely that a successful process can be developed for fabrication of large truss core panels.

2) Techniques should be developed for fabrication of Be/Ti composite panels and Be/Be truss core panels entirely by the resistance spot brazing techniques. Using these techniques, demonstration panels (Be/Ti and Be/Be) should be fabricated with the available corrugated Be core and Ti and Be face sheets.

3) A program should be established to develop improved quality beryllium ingot sheet. Emphasis should be given to sheet quality (i.e. surface finish, flatness, thickness variations), formability and fracture toughness of the beryllium ingot sheet.

4) At such time as improved quality beryllium sheet becomes available, a structural evaluation program should be conducted on beryllium-titanium composite panels.